BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

[redacted]

SUBJECT: S-II 27 Degree-of-Freedom Longitudinal Structural Model - Case 320

DATE: May 23, 1969

FROM: H. E. Stephens

ABSTRACT

A 27 degree-of-freedom uniaxial longitudinal structural model of the Saturn 5 Configuration II (S-II plus upper stages) has been assembled. Longitudinal structural modal data have been generated using the AS-504 fuel loading and are included. The response frequencies observed during S-II burn have been reasonably well duplicated, as has the inboard engine gain at the time of maximum acceleration. The flight observed phase angle relationship between the LOX tank and inboard engine has not been duplicated.

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(NASA-CR-103641) S-2 27-DEGREE-OF-FREEDOM LONGITUDINAL STRUCTURAL MODEL (Bellcomm, Inc.) 14 p

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MEMORANDUM FOR FILE

1. After the AS-504 flight, longitudinal structural modal data that would duplicate flight data were not available, nor were the MSFC or Boeing longitudinal structural models available. A uniaxial longitudinal model of configuration II (S-II up) was assembled to do a limited parametric variation to obtain a set of computed modal data that would approximate the flight response. Information contained in References 1 through 6 was used as a basis for the model, which consists of 27 degrees-of-freedom, and is shown in Figure 1. Only a single degree-of-freedom is used for each the S-II LOX and LH_2 masses. The time variant equivalent LOX tank spring constant duplicates the first LOX tank mode (as seen in the MINI-A Test) in the early flight times, and the second mode in the later flight times. The time variant propellant masses and spring constants are given in Table I.

2. AS-504 modal data were calculated for 15 time points during S-II burn, and the frequency versus time curves are shown in Figure 2. The association of the time base of these curves with an early center engine cut-off involves only a 20% expansion of the time scale after center engine cut-off. The inboard and outboard engine gains* are given in Figures 3 through 6 for the first eight elastic modes in g's/pound. The acceleration response spectra, based on nine elastic modes, for the inboard engine and LOX c.g. at T = 345 seconds are shown in Figure 7, with the corresponding phase angles given in Figure 8.

3. Salient features of the observed flight data were:

a. A maximum inboard engine acceleration of 12 g's, zero to peak, at about T = 342 seconds and 16.8 cps.

b. A thrust chamber pressure variation of 25 psi at the time of maximum acceleration, zero to peak.

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*Gain for n^{th} mode is defined as:

$$\frac{(\text{Engine Eigenvector Coordinate, } n^{th} \text{ mode})^2}{(\text{Generalized Mass})\ g}$$

c. A LOX tank bottom acceleration of 8 g's at the time of maximum inboard engine acceleration, which was in phase with the inboard engine.

d. An inboard engine acceleration response frequency increase from 16.8 cps at T = 342 seconds to 19 cps at burnout, with the measured phase angles indicating that the vehicle response frequency during this period corresponded to that of a structural mode.

4. Correlation of the computed data with flight data is as follows:

a. There is a computed structural mode varying in frequency from 16.5 cps at T = 342 seconds to 18.9 cps at burnout, comparable to the 16.8 to 19 cps flight data.

b. Using the 1.5% pre-flight value of damping, the computed maximum inboard engine acceleration is:

$$\frac{(\mathrm{GAIN})}{2(\zeta)}\left(\frac{P}{TC}\right)(F)=\frac{(5.3 \times 10^{-5})}{2(.015)}\left(\frac{25}{650}\right)(200{,}000) = 13.6 \text{ g's}$$

Where:

GAIN = 4th mode inboard engine gain (g's/lb) at T = 342 seconds.

ζ = % critical damping/100

P = maximum thrust chamber pressure variation

TC = thrust chamber pressure at T = 342 seconds

F = Thrust at T = 342 seconds.

This computed 13.6 g's compares with a measured value of 12. Use of 1.7% critical damping, vice 1.5%, would bring the computed and measured values into agreement.

c. Figure 7 represents the T = 345 seconds combined acceleration response from the first nine elastic modes. It is thus determined that at the 16.7 cps maximum response peak, the LOX c.g. acceleration, which should correspond to the tank bottom acceleration at this time, is .45 of the inboard engine acceleration. This value of .45 compares to a flight measured ration of .67.

d. The one relationship that could not be duplicated with this single degree-of-freedom tank representation was the phase angle between the LOX tank and engine during the T = 342 seconds to burnout period. As seen in Figure 8, at the frequency of interest, 16.7 cps, the two accelerations are out of phase; whereas flight data showed them to be in phase. To date, structural models by other agencies, which include multi degree-of-freedom tanks have not duplicated the flight measured phase angles. Enough of a parametric study was done to conclude that the desired phase angles are not obtainable with a single degree-of-freedom tank representation. Others within Bellcomm are now pursuing a multi degree-of-freedom LOX tank representation retrofitted into the model of Figure 2. It is noted that the desired phase angle relationship between inboard engine, outboard engines, and LOX tank does appear in the high gain thrust structure mode of about 21 cps.

e. Although the comparison is not included herein, the computed frequencies agree well with the other response frequencies observed throughout the AS-504 flight.

H. E. Stephens

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Attachments
Figures 1 - 8

AS-504 S-II TIME VARIANT PROPELLANT
WEIGHTS & SPRING CONSTANTS

	(LBS) LH_2 Wt x 10^{-4} (Includes 2100 lb struct)	(LBS) LOX Wt x 10^{-4} (Includes 2600 lb struct)	K25 LH_2 #/in x 10^{-6}	K26 LOX #/in x 10^{-6}
0	15.774	81.947	1.4	5.8
40	14.1	72.885	1.47	5.75
80	12.41	63.588	1.55	5.7
120	10.921	54.549	1.65	5.65
160	9.21	45.242	1.75	5.4
200	7.505	35.924	1.8	4.5
240	5.749	26.595	1.9	3.7
280	4.084	17.296	2.0	2.7
300	3.261	13.278	2.1	2.28
320	2.448	9.454	2.15	1.8
340	1.634	5.661	2.2	1.5
345	1.431	4.662	2.25	1.4
350	1.228	3.717	2.3	1.25
360	.8237	2.239	2.35	.8
370	.535	.542	2.4	.48

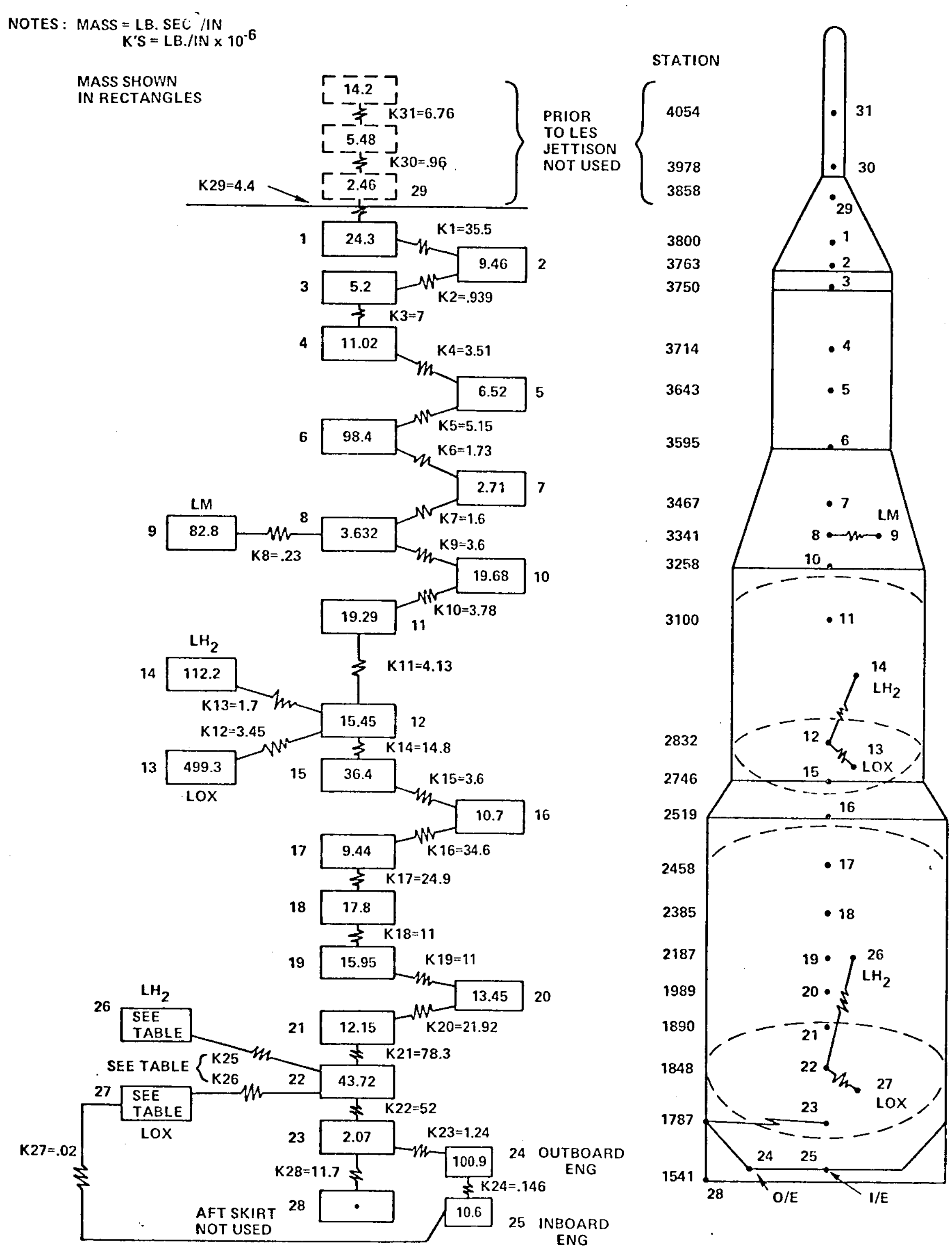

FIGURE 1 - AS 504 CONFIGURATION III LONGITUDINAL MODEL, 27 DOF

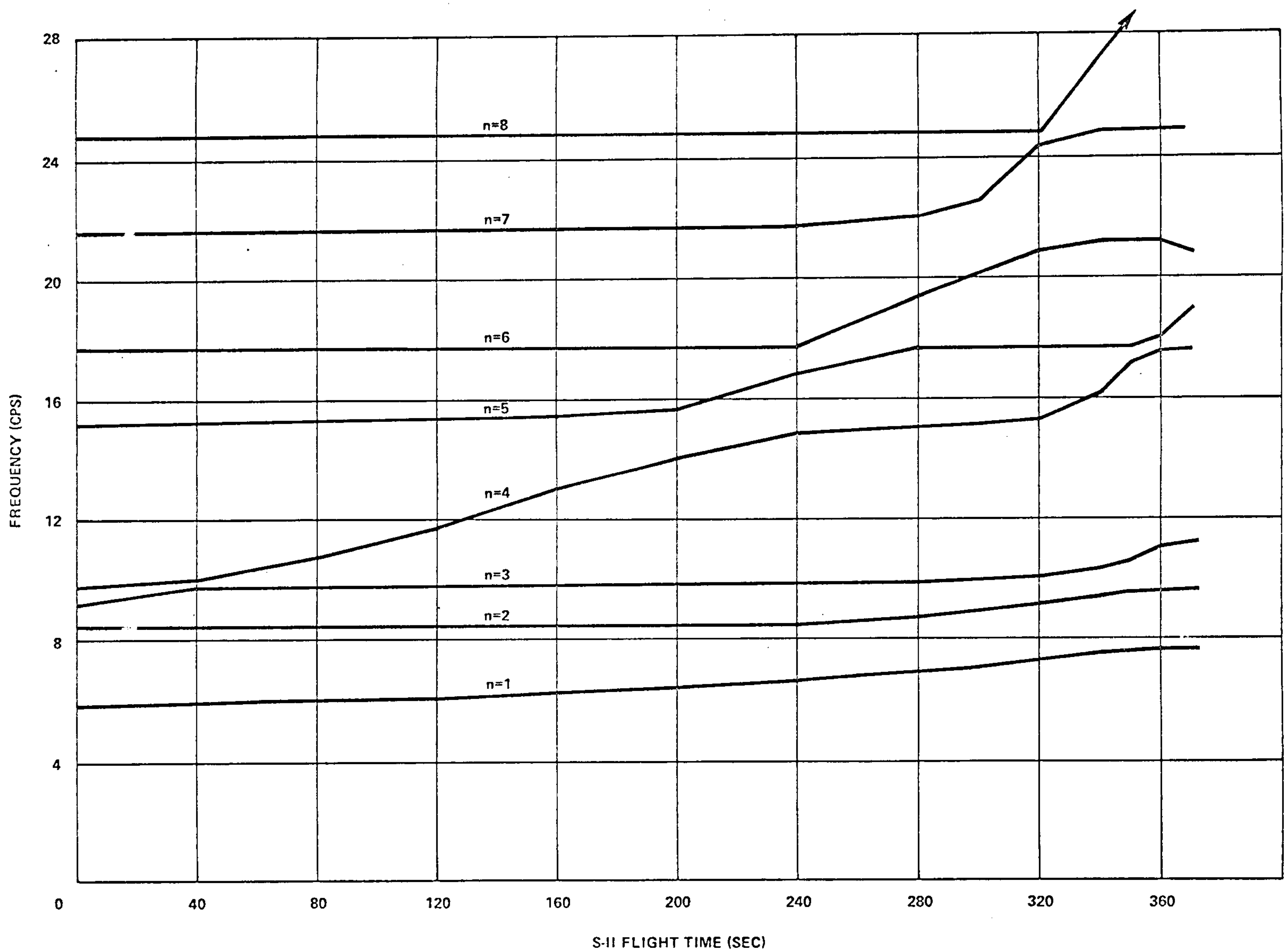

FIGURE 2 -AS 504 - S-II - LONGITUDINAL FREQUENCIES VS TIME
BELLCOMM 27 DOF MODEL 5/7/69

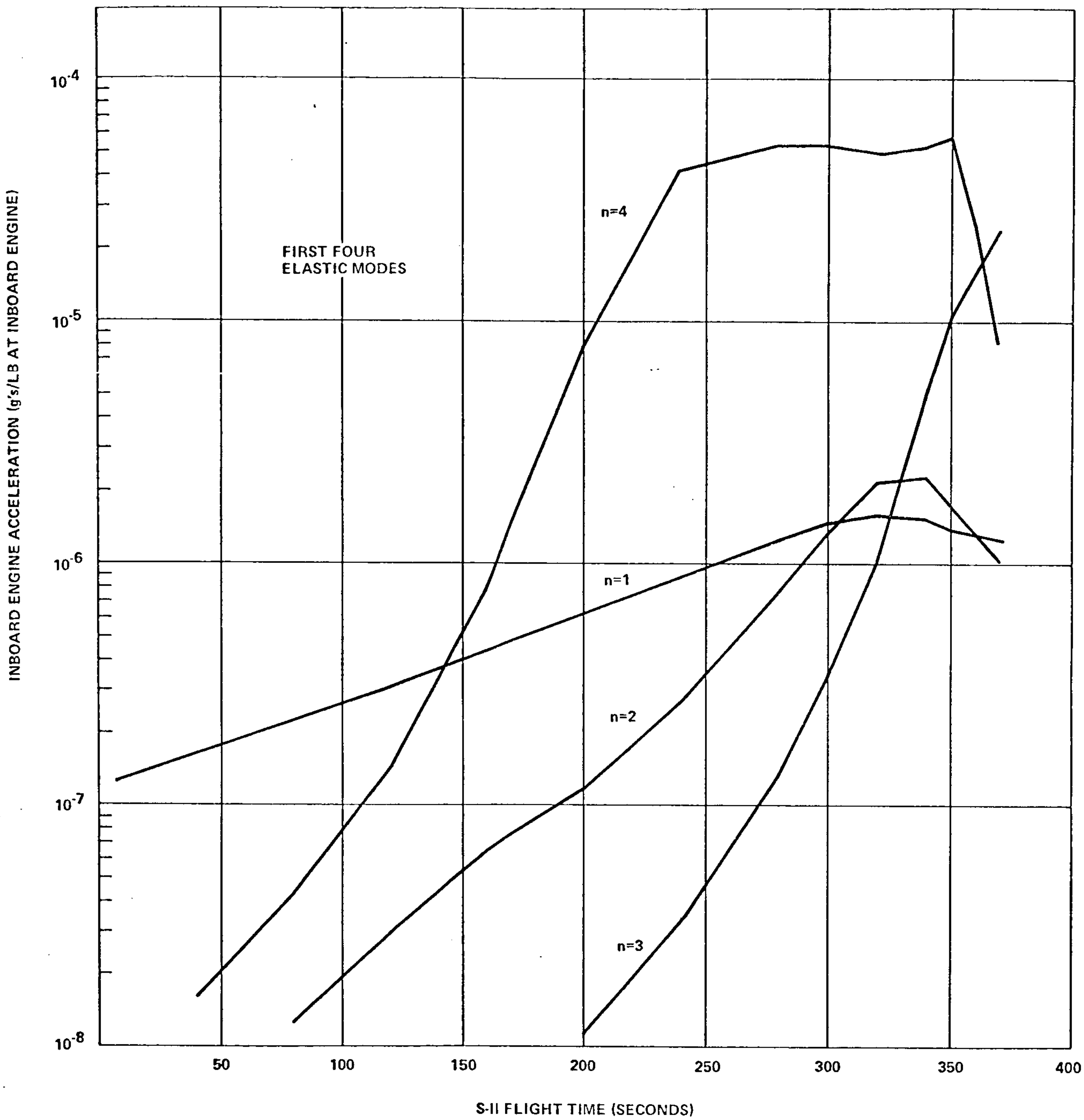

FIGURE 3 - AS 504 S-II INBOARD ENGINE GAINS. BELLCOMM 27 DOF MODEL

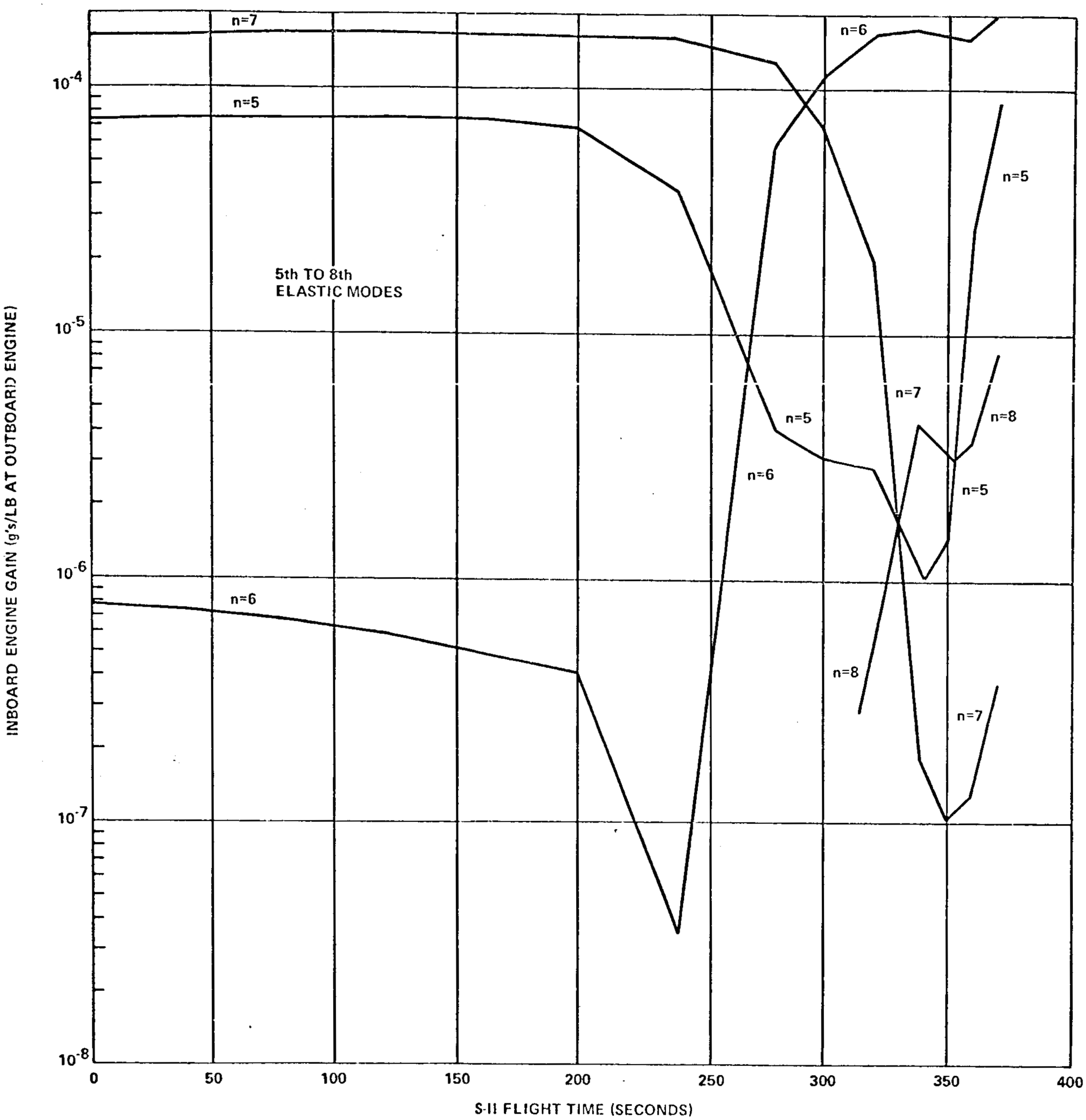

FIGURE 4 - AS 504 S-II INBOARD ENGINE GAINS. BELLCOMM 27 DOF MODEL

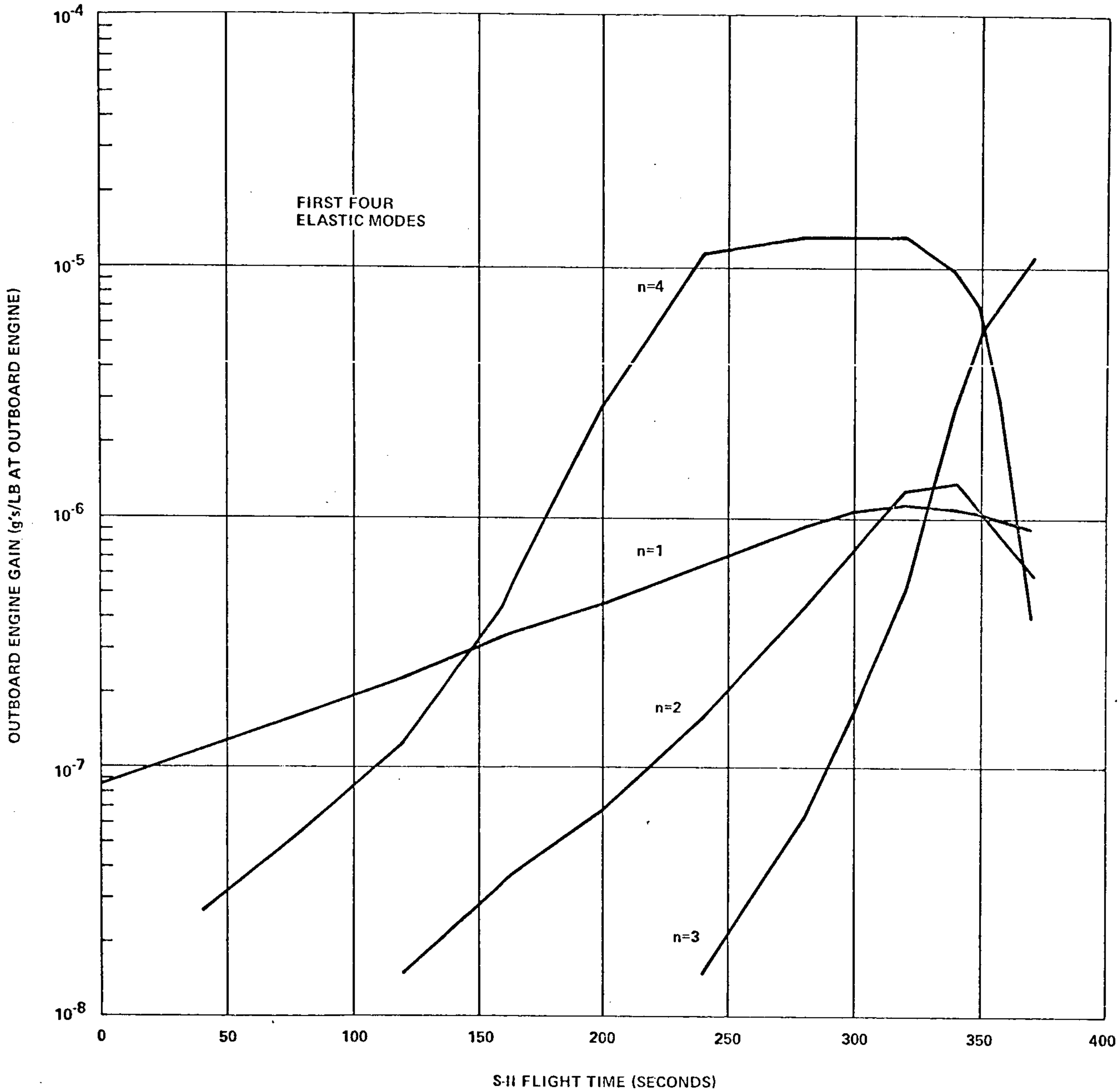

FIGURE 5 - AS 504 S-II OUTBOARD ENGINE GAINS. BELLCOMM 27 DOF MODEL

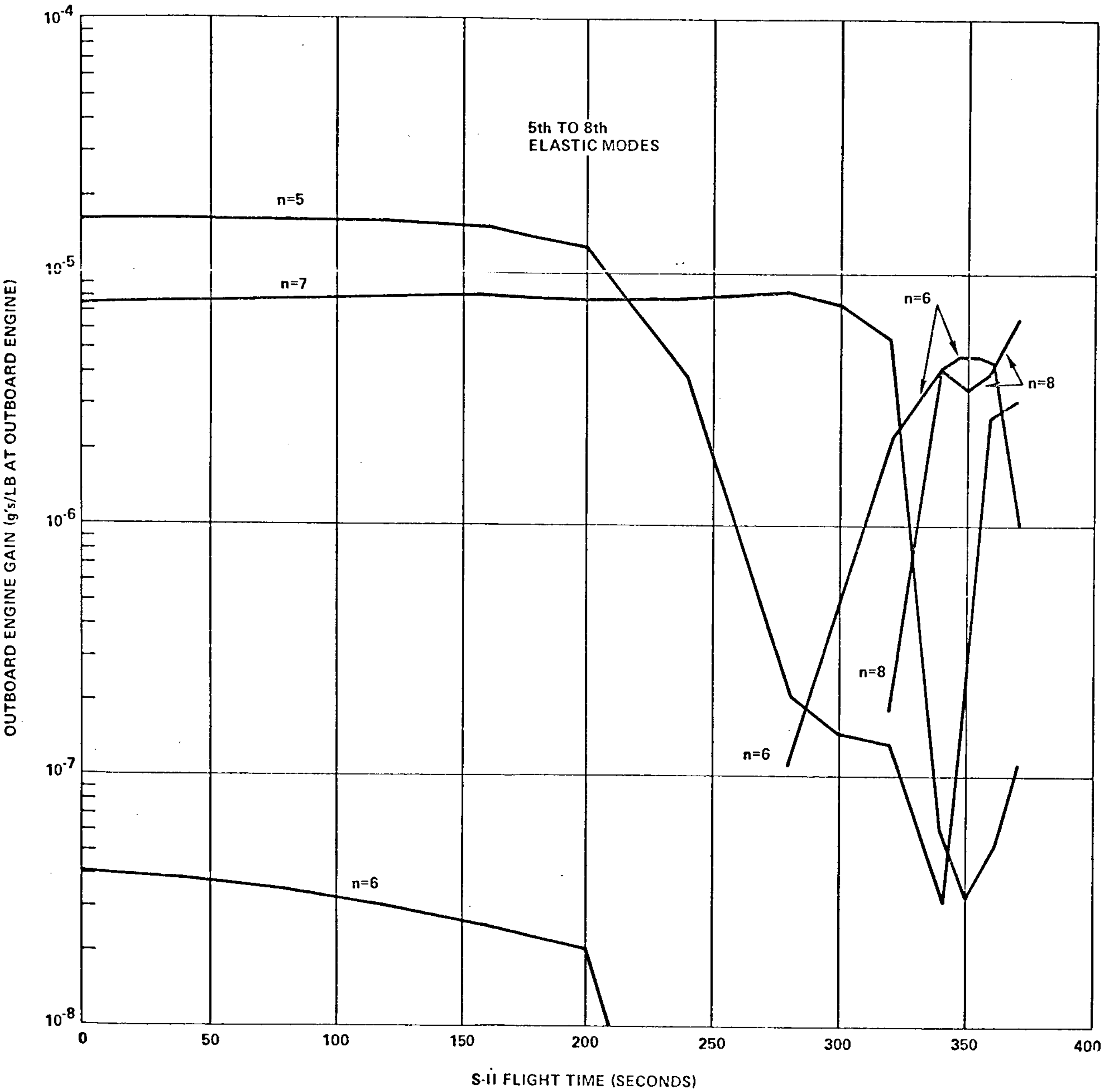

FIGURE 6 - AS 504 S-II OUTBOARD ENGINE GAINS. BELLCOMM 27 DOF MODEL

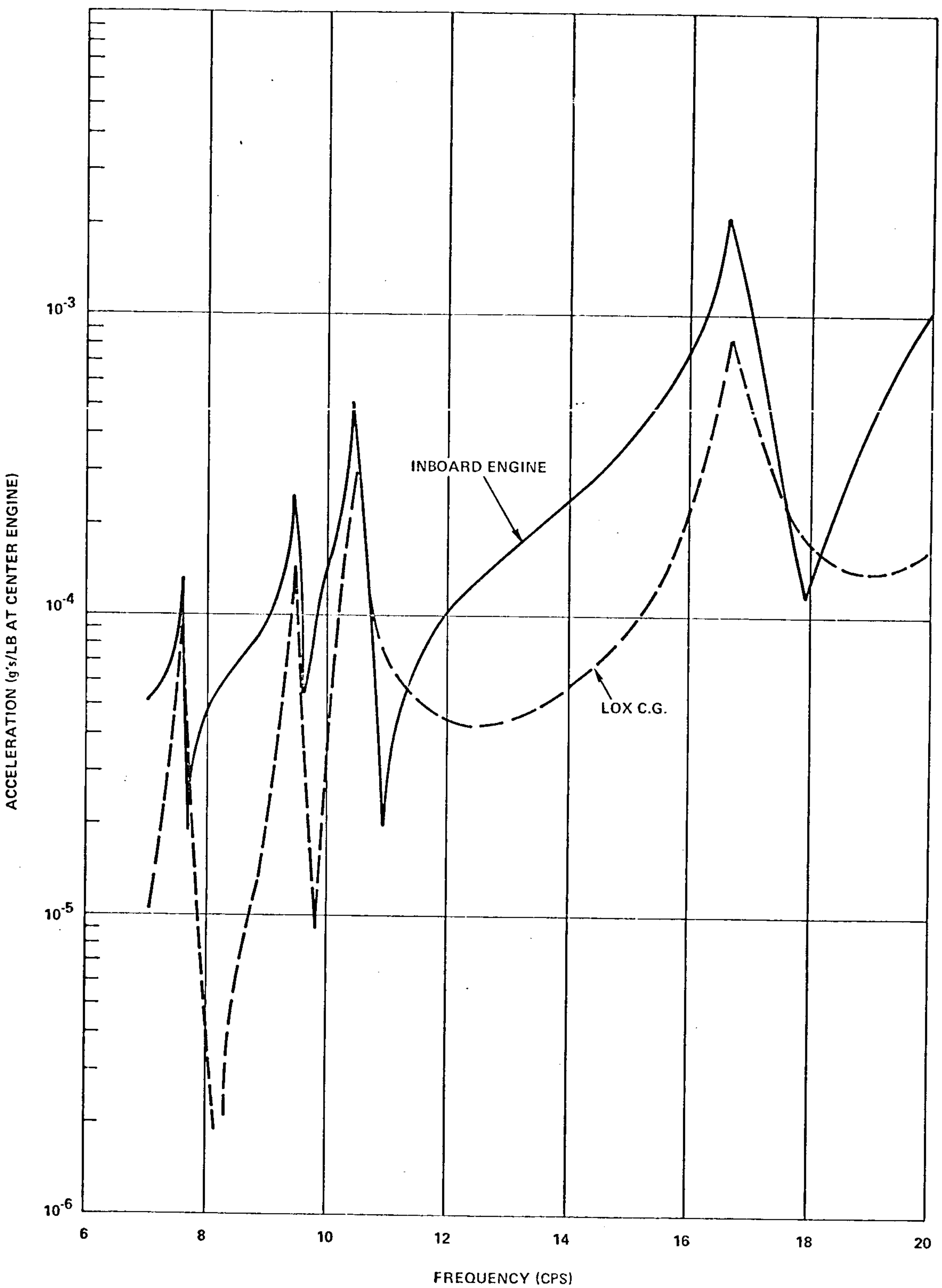

FIGURE 7 - AS 504 S-II INBOARD ENGINE & LOX C.G. LONGITUDINAL ACCELERATION. T = 345 SECONDS

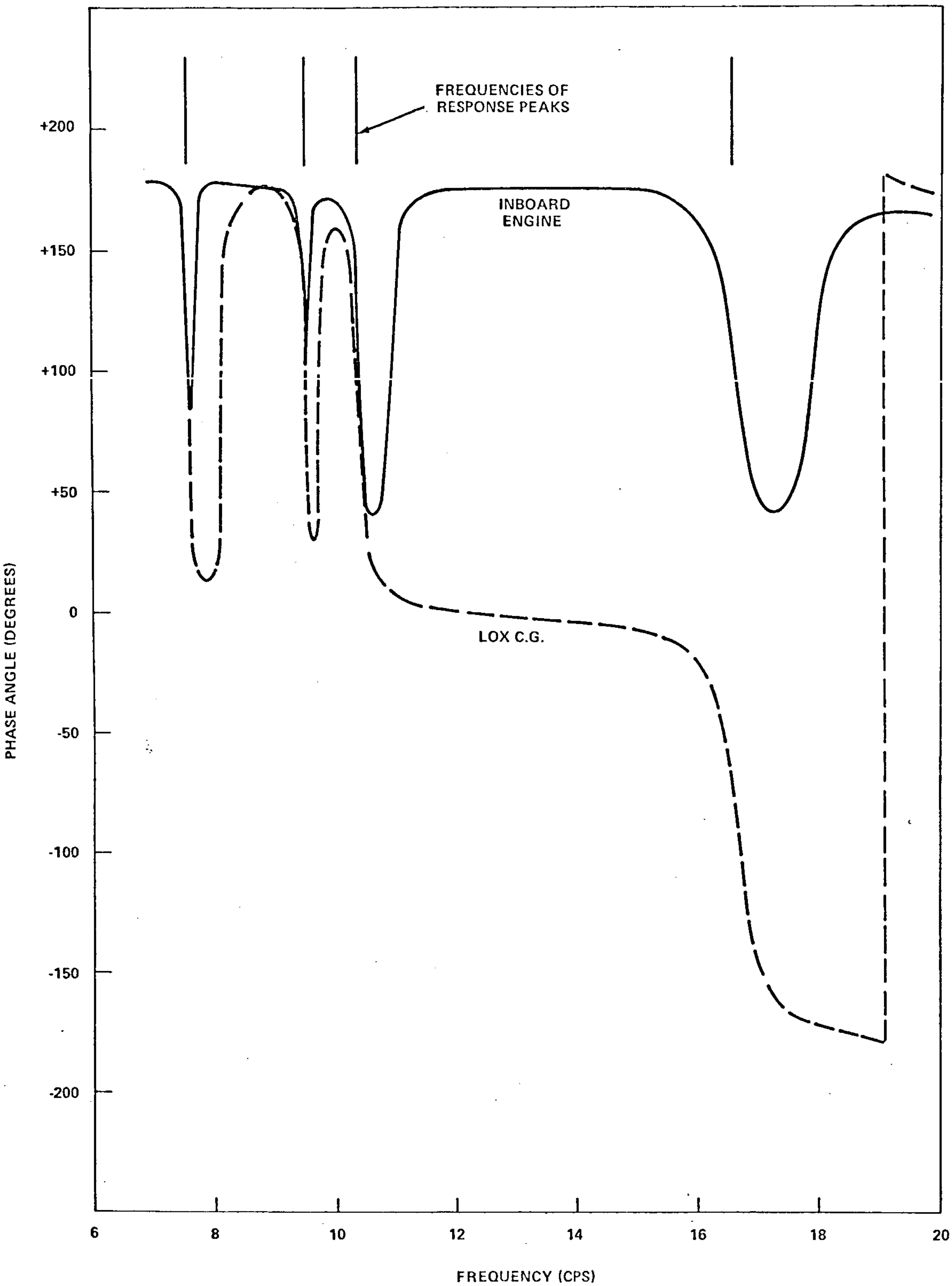

FIGURE 8 - AS 504 S-II INBOARD ENGINE & LOX C.G. LONGITUDINAL ACCELERATION PHASE ANGLE. T = 345 SECONDS

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REFERENCES

1. SA-503 "Manned" Longitudinal Structural Dynamic Characteristics, by Boeing Huntsville, July 17, 1968, 5-9570-JH-395.

2. Influence of Weight Changes on AS-503 Structural Longitudinal Modes, Shopes and Frequencies, Case 320, September 10, 1960. H. E. Stephens.

3. Saturn V AS-504 Coupled Dynamic Characteristics by Boeing Huntsville, December 2, 1968, D5-15774-4.

4. Memorandum Source Data Parameters for AS-504 S-II Boost Stability Studies, by Boeing Huntsville, February 24, 1969, 5-9540-H-782.

5. Informal information on North American structural representation of S-II Stage.

6. Boeing document No. D5-15206-3-TN, Configuration III SA-500D Dynamic Analysis of 5/65.